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Covering the Period 08 July 2010 through 07 July 2013

ASSIMILATION OF WAVE AND CURRENT DATA FOR PREDICTION OF INLET AND RIVER MOUTH DYNAMICS

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14. ABSTRACT

Coastal inlets and river mouths exhibit large magnitude currents and current gradients and together with nearshore waves create a dynamic environment with strong nonlinear interactions. These interactions and the resulting environmental conditions can be predicted using models such as the SWAN and Delft3D, but the fidelity of the predictions can be limited by the accuracy of the specification of boundary conditions, initial conditions, and forcing. This program developed variational algorithms to assimilate local data for waves, tides, and currents to improve these uncertain model inputs and thereby bring predictions into agreement with the data

15. SUBJECT TERMS

Variational inversion, data assimilation.

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EXECUTIVE SUMMARY

This report covers activities under Office of Naval Research Contract No. N00014-10-C-0507 for the period from 08 July 2010 through 07 July 2013. At the Program Officer's request, this report has been prepared in the form of a final briefing that was presented on 25 April 2013 at the Rivet Results Meeting at the Navy League in Arlington, Virginia.

Coastal inlets and river mouths are chokepoints in both a tactical and hydrodynamic sense. Large-magnitude currents and current gradients, and their interactions with near-shore waves, create a dynamic environment with strong nonlinear interactions. These interactions and the resulting environmental conditions can be predicted using models such as the SWAN and Delft3D, but the fidelity of the predictions is limited by approximations in both the models and the model inputs, including boundary conditions, initial conditions, and forcing. The ability to adjust uncertain model inputs to bring predictions into agreement with the data is desirable and data assimilation is a practical way to accomplish this.

The overall goal of this research program was to develop methods for using local data to improve predictions from high-resolution nearshore wave and circulation models. The specific objectives were to develop three things: an approach for nesting Delft3D in arbitrary circulation models, a method for assimilating tide and velocity data in Delft3D for estimation of improved boundary and initial conditions, and a method for assimilating wave spectrum observations into the SWAN model executed in Delft3D.

A necessary part of a capability to carry out accurate, high-resolution modeling of the nearshore region is the ability to extract initial and boundary condition information for Delft3D from operational forecast fields. This nesting of Delft3D in operational forecasts was accomplished through interpolation of the operational forecast fields onto the Delft3D computational grid and the specification of Riemann-type boundary conditions for the boundary-normal velocity and surface elevation, as well as salinity and temperature boundary conditions. To allow complete specification of the boundary conditions, the Delft3D code was modified to allow the tangential velocity at boundary to be set as well (this modification has been provided to Deltares, for inclusion in upcoming open-source community model updates). Results of the nesting approach are shown below for the NOAA Real Time Operational Forecast System (RTOFS—based on the Navy HyCOM model) for the area around the New River Inlet during May 2012. Scripts have also been developed for nesting of Delft3D in low-resolution, large-scale Delft3D model results, and under separate funding, the Navy Coastal Ocean Model (NCOM).

We developed algorithms for estimation of improved tidal boundary conditions from point observations of sea-surface elevation and for estimation of improved velocity boundary conditions from in situ or remotely sensed velocities. An adjoint-based assimilation algorithm was developed to estimate improved sea-surface-elevation boundary conditions from time-history data from in situ tide gages. The corrections are applied to the surface-elevation contribution to the Riemann boundary conditions. The boundary conditions are shown to effectively converge in one iteration using observed tides near the New River Inlet in May 2012. Development of the adjoint-based assimilation algorithm for using velocity observations to improve circulation (velocity) boundary conditions for Delft3D is complete; however it has yet to be applied to field data. Results for simulated data are shown below. The only New River

Inlet data that we have obtained for use in this algorithm is interferometric synthetic aperture radar data (from the University of Washington Applied Physics Laboratory). This data became available too late in the program to be processed, but will be the focus of future efforts.

In addition to the above, we developed an algorithm for using wave-buoy data to estimate offshore boundary conditions for the SWAN model. This can be run either as a stand-alone tool for estimation of waves alone, or embedded in Delft3D to capture wave-current interactions and wave-induced circulation. This algorithm matches the SWAN wave estimate to the waves at the level of the Fourier directional spectrum coefficients, and does not require reconstruction of the directional spectra from the buoy data. This algorithm was applied to nearshore Waverider buoy data for the New River Inlet in May 2012, and the estimated wave spectra for the region were validated by comparison to independent wave spectrum data in the region.

The algorithms described above are all of the strong-constraint variational variety, and make use of adjoint solvers corresponding to the various model equations, all rigorously derived. The briefing below focuses on the algorithm results, mainly for real-world data. A complete description of the mathematics underlying the algorithms has been reported in various quarterly reports, and is presently being prepared for publication. Future activities will focus on further validation and refinement of the algorithms developed here using data collected at the New River Inlet and at the mouth of the Columbia River. Complete integration of the wave, tide, and circulation algorithms into a single flexible package, capable of using any/all available data to improve model predictions in complicated nearshore environments, will also be the focus of future work.

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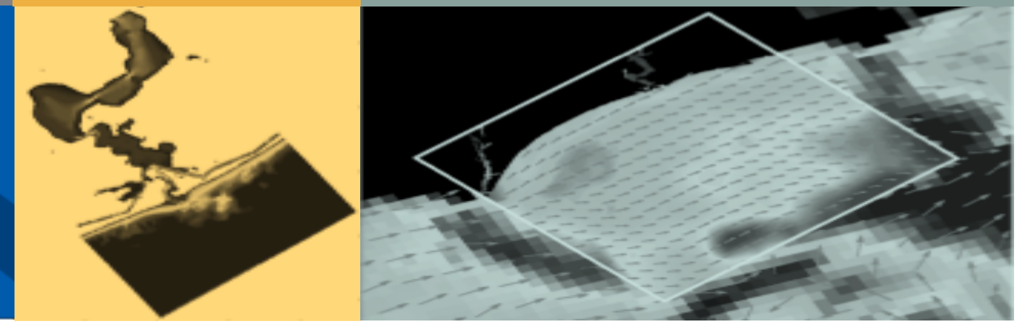


Assimilation of Data in Delft3D/SWAN for the New River Inlet

David Walker, Tom Almeida, Matthew Masarik & Arie Reath

SRI International, Ann Arbor MI

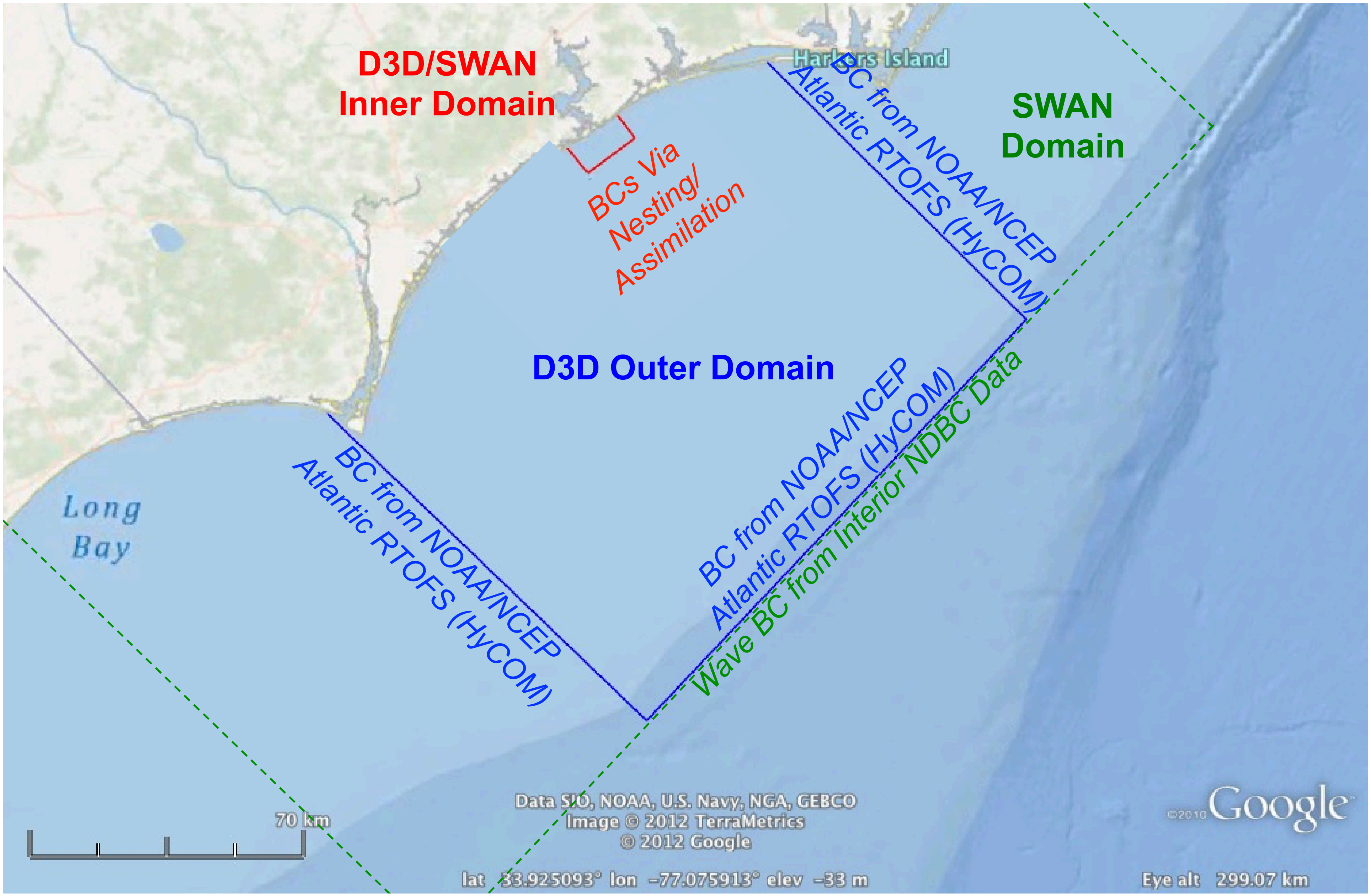
Supported by ONR Contract No. N00014-10-C-0507

Goals and Objectives

- Goal: To develop methods to use local data to improve predictions from high-resolution nearshore wave and circulation models

- Objectives are to develop:
  - An approach for nesting Delft3D in arbitrary circulation models
    - Use of boundary conditions based on Riemann invariants
    - Addition of tangential velocity boundary conditions to Delft3D-FLOW v5
    - Nesting codes/scripts for RTOFS (HyCOM), NCOM, Delft3D
  - Assimilation methods for tide and circulation IC/BCs
    - In-situ point sea-surface elevation observations
    - Remote-sensing vector velocity field measurements
  - Assimilation method for in-situ wave spectrum observations
    - Fourier directional coefficients from typical sensors (Waveriders, discus buoys)
    - Estimate boundary spectra for SWAN
  - A single, unified algorithm for coupled wave/tide/circulation estimation using local data

Nominal Model Domains for the New River Inlet



SWAN assimilation for Onslow Bay and the New River Inlet

- SWAN Grid
  - 295 km x 156 km (589 x 311, 500m grid spacing)
  - 48 directions, 50 frequencies (7.5 deg, 0.025-0.5 Hz, log spacing)
- Inputs
  - Bathymetry from NGDC Coastal Relief Model (3 arc-sec)
  - Tides are average of NOS Stations 8656483 and 8658163
- Time stepping: Quasi stationary at 6-hr intervals
- Boundary conditions
  - Offshore boundary: Uniform spectrum
  - Lateral boundaries: Linear ramp to zero

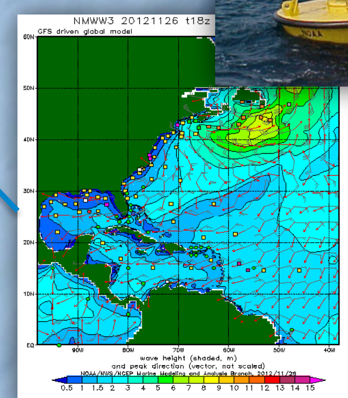
Assimilation

- Offshore boundary spectrum estimated for each time
- Data source: NDBC 41109 and 41110 Fourier coefficients (a0, a1, b1, a2, b2 vs. f)
- 30-40 min required for each BC estimate (on 32 Intel Xeon cores)

AWAC Spectra Raubenheimer/ Elgar - WHOI

Datawell Buoys
- State of North Carolina
- McNinch -USACE FRF

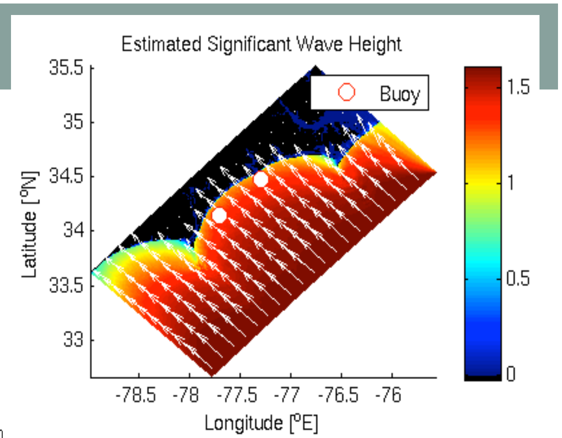
NDBC 3m Discus Buoy



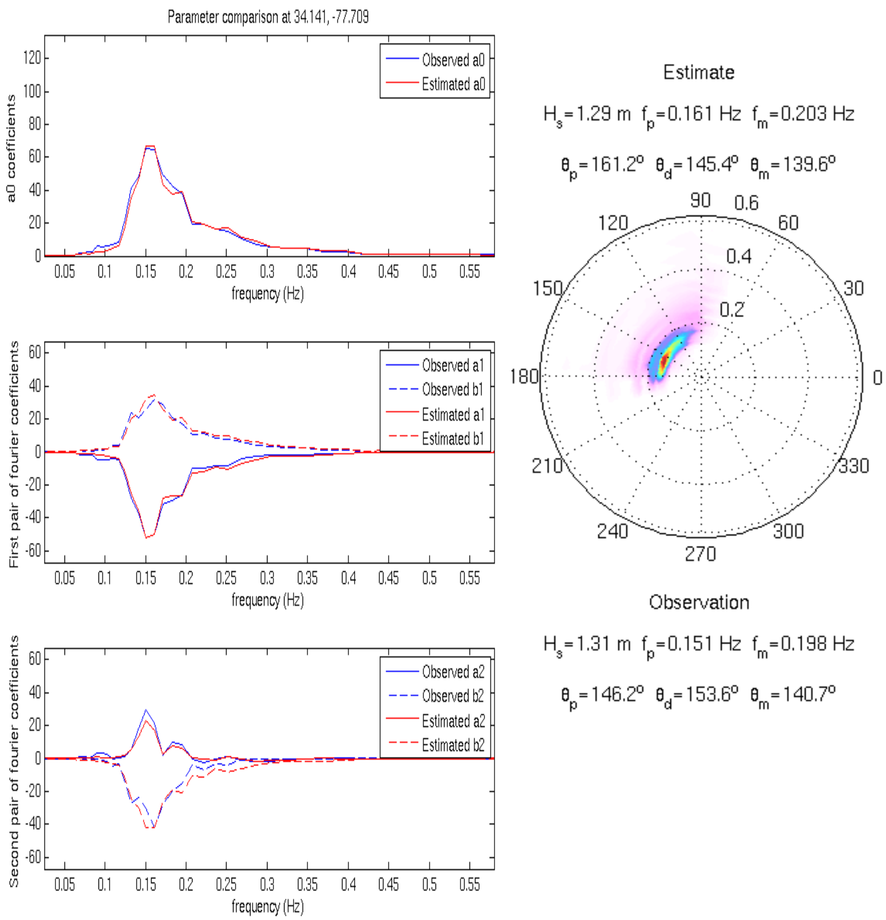
FNMOC Global Wavewatch 3

New River Inlet SWAN assimilation

05/15/2012 at 00:00 GMT



NDBC 41110



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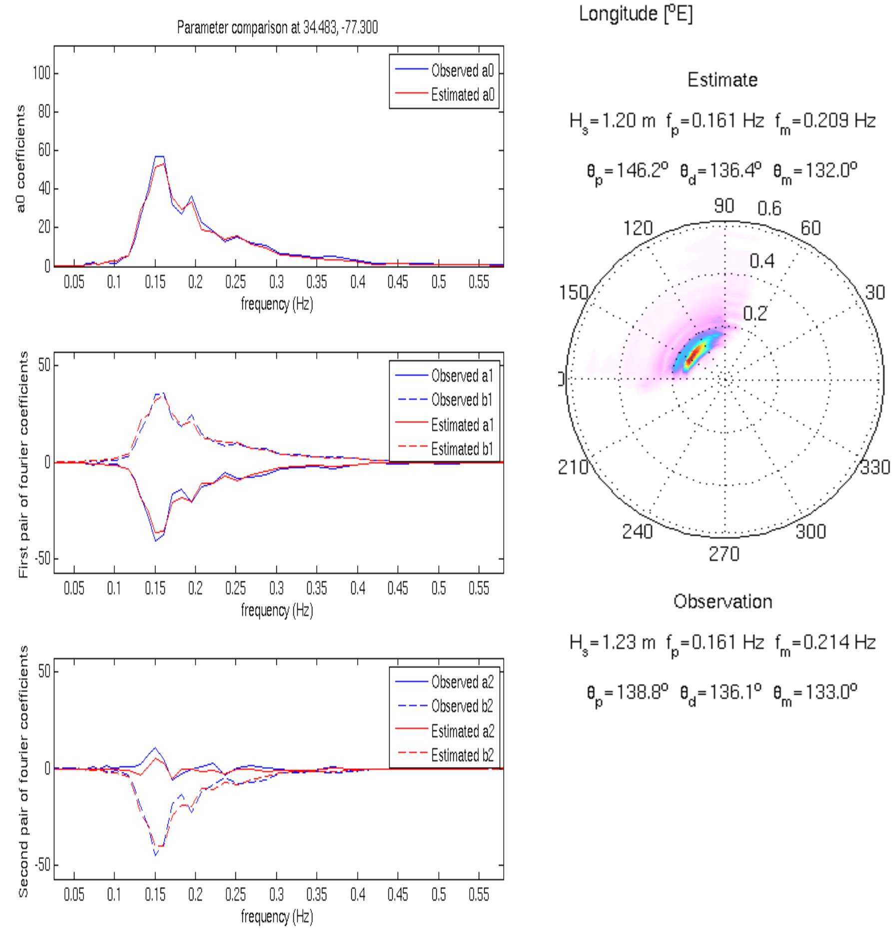
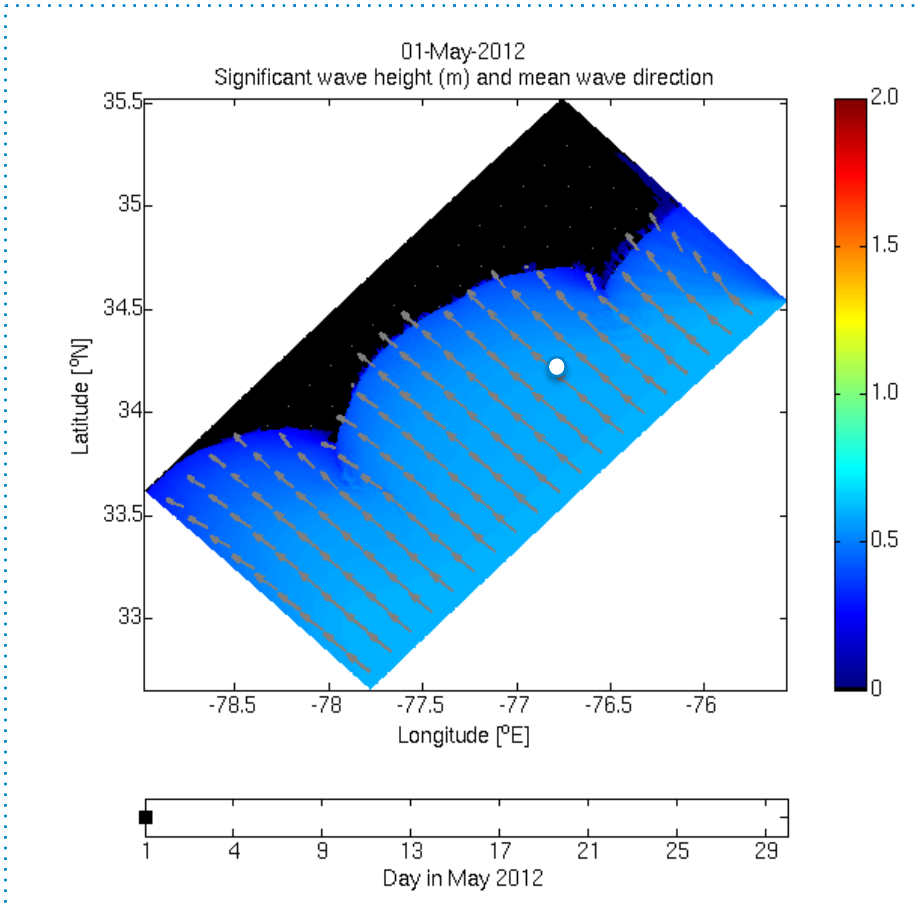
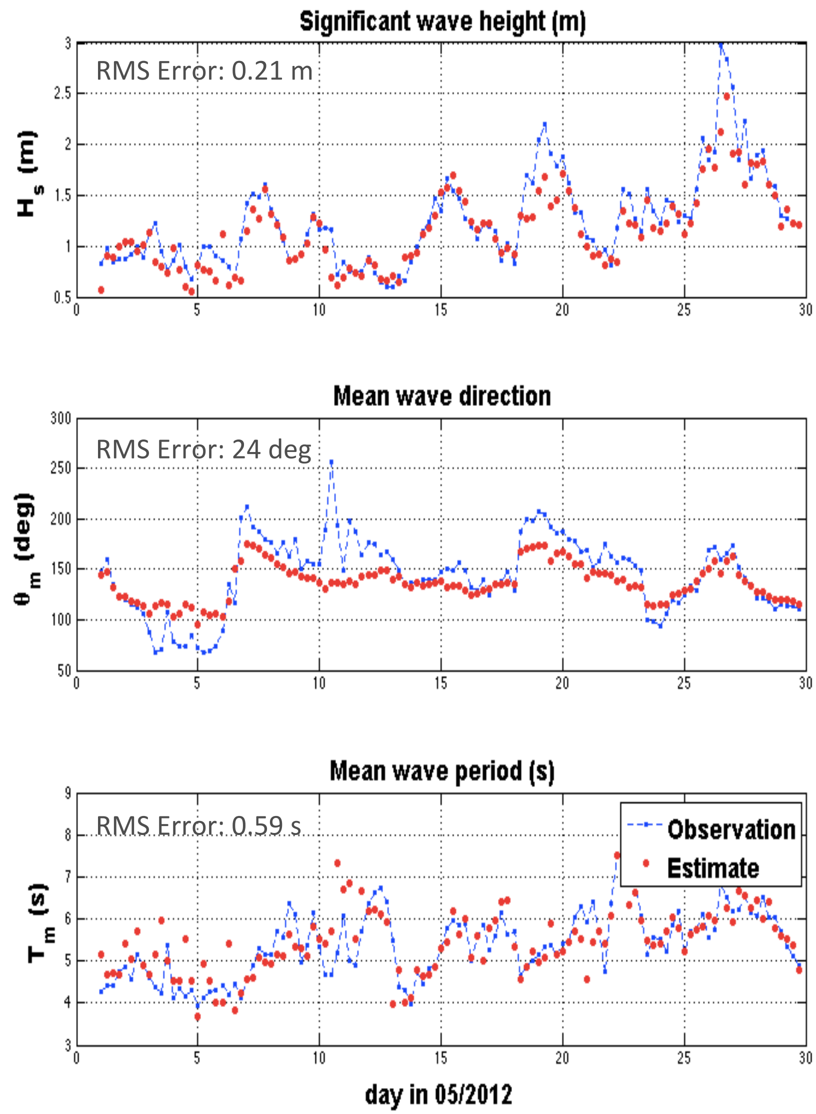


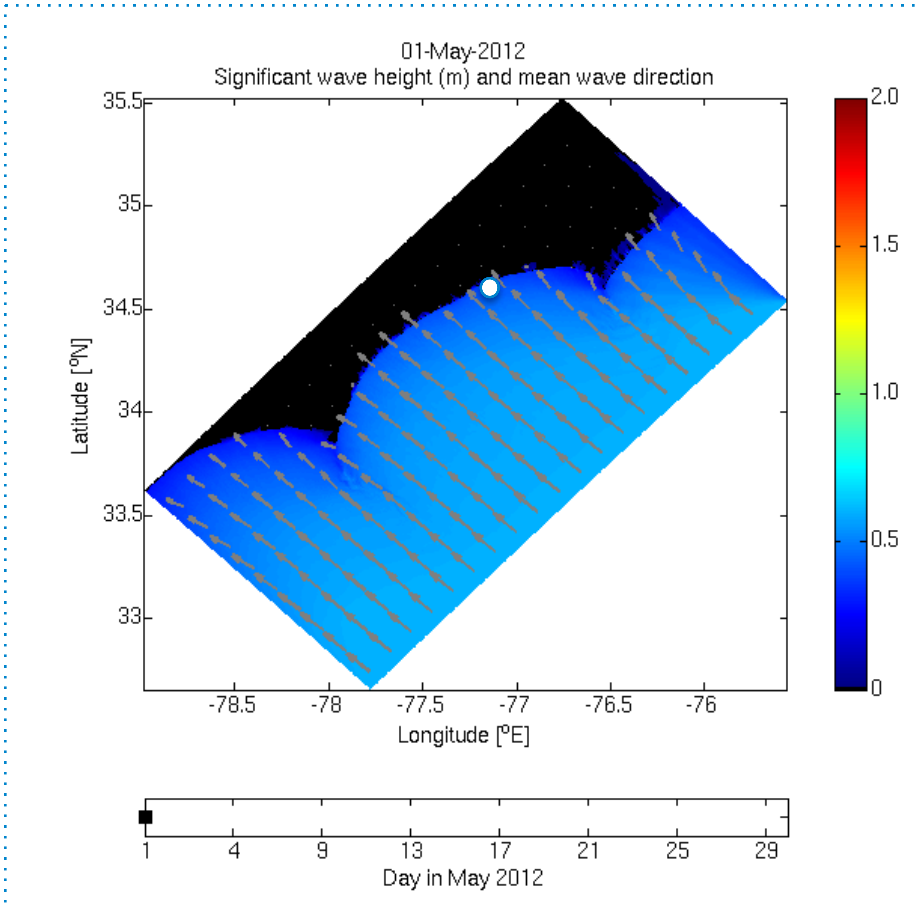
Estimated SWAN Wave Solution in Outer Domain



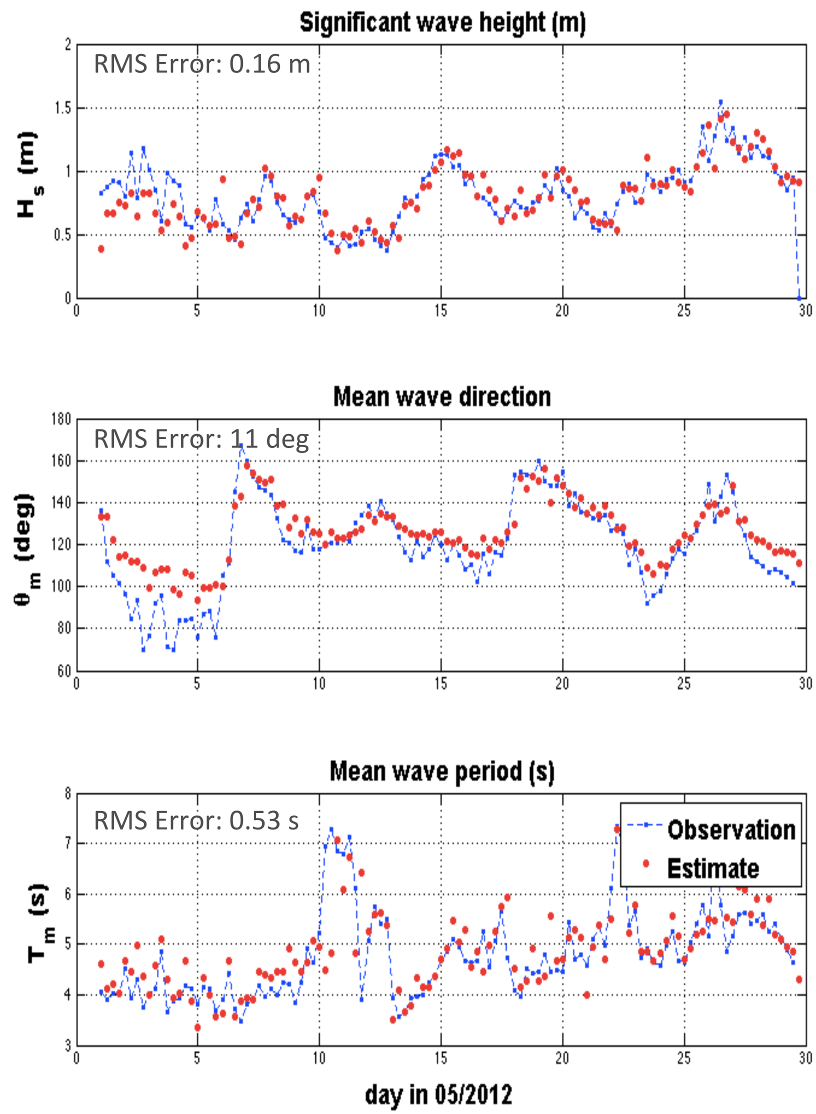
Wave comparisons at NDBC 41036



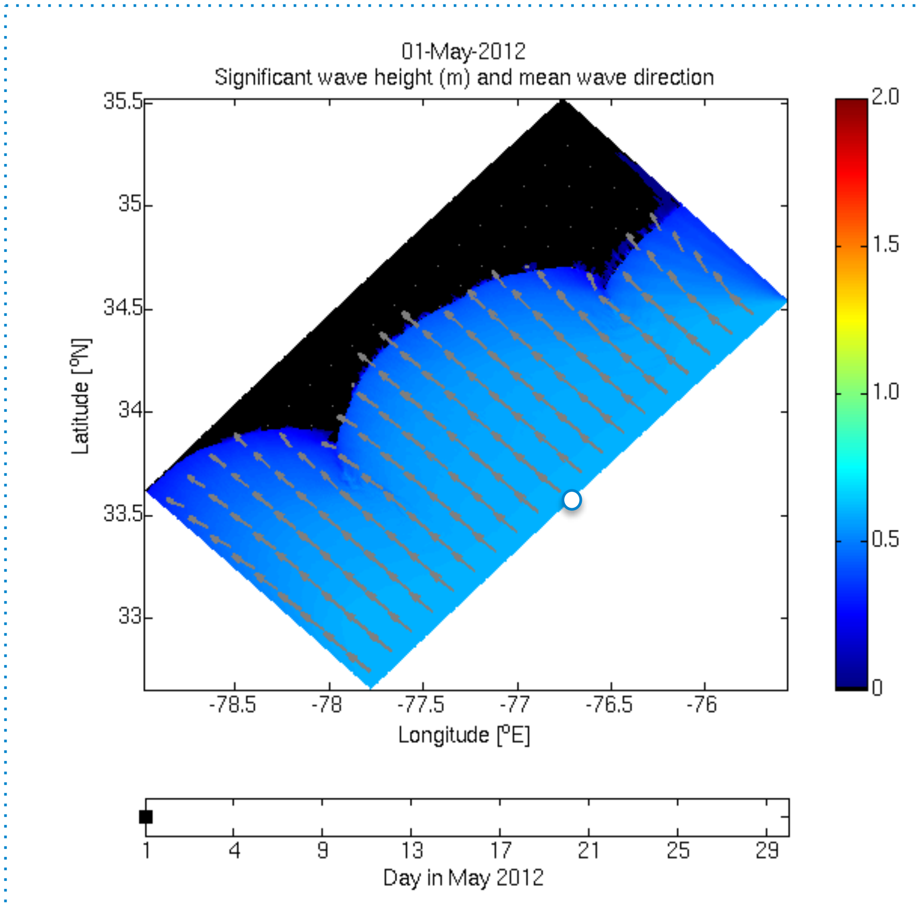
Estimated SWAN Wave Solution in Outer Domain



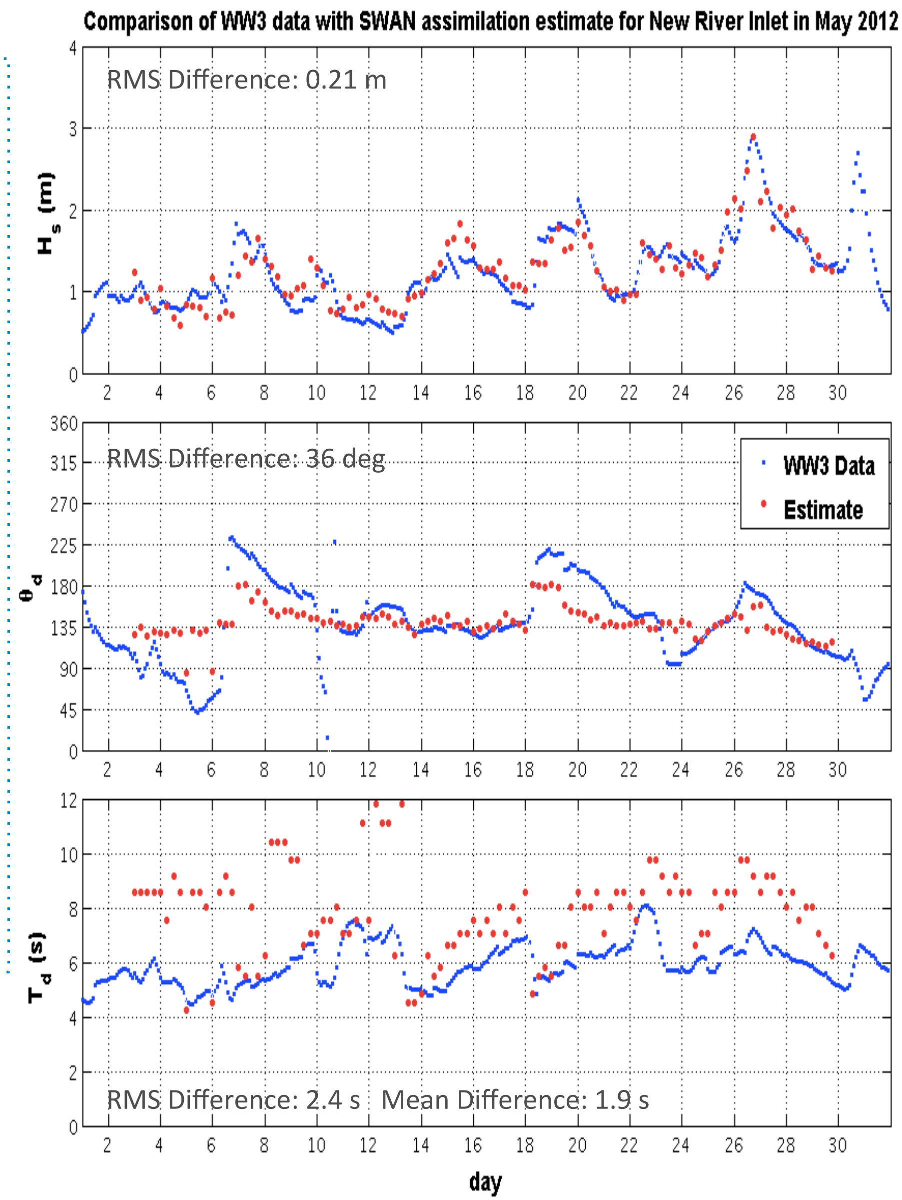
Wave comparisons at WHOI-191702



Estimated SWAN Wave Solution in Outer Domain

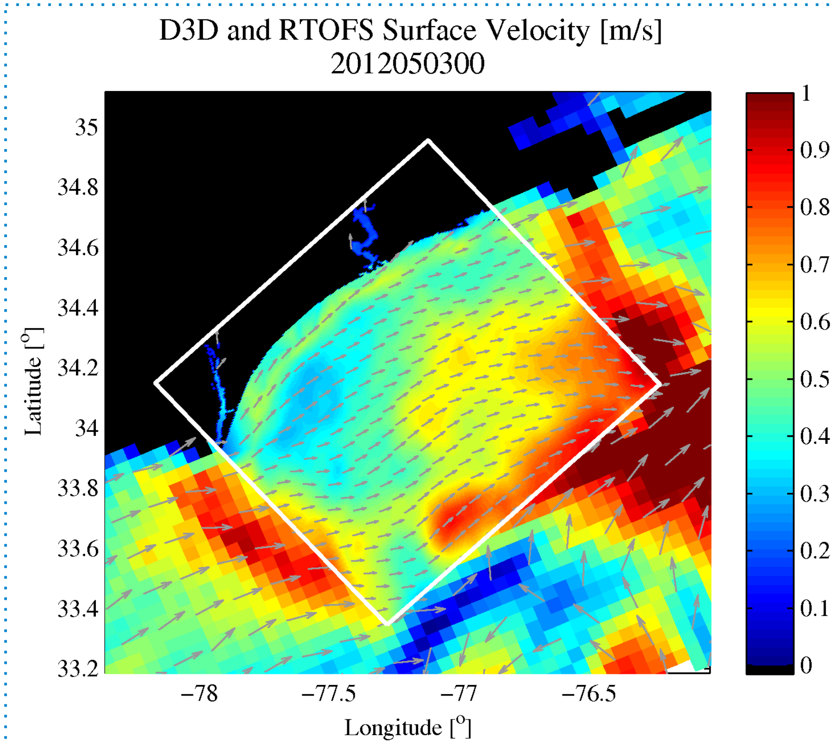


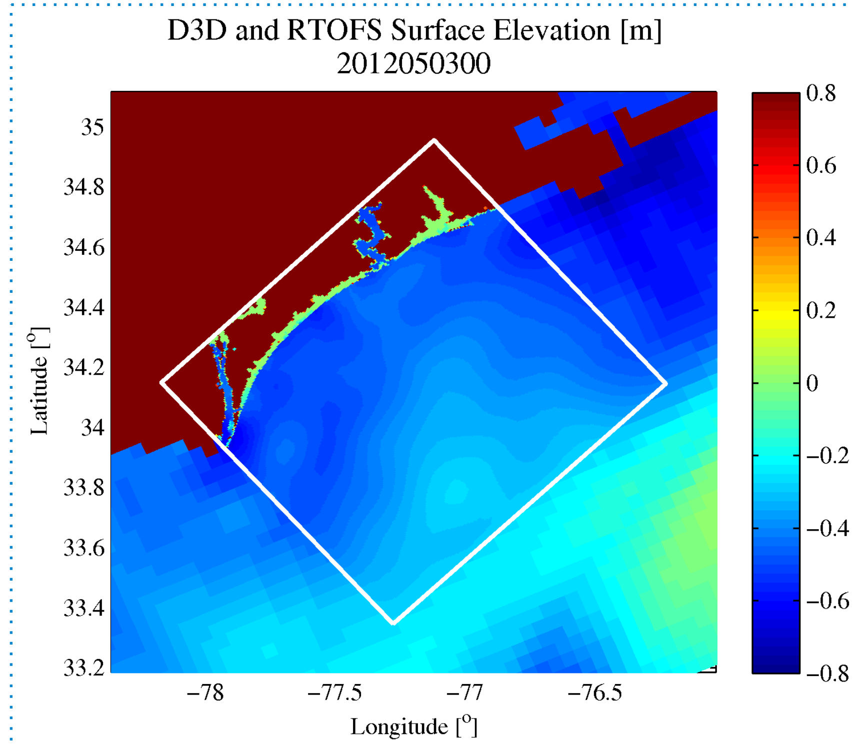
FNMOC Global WW3



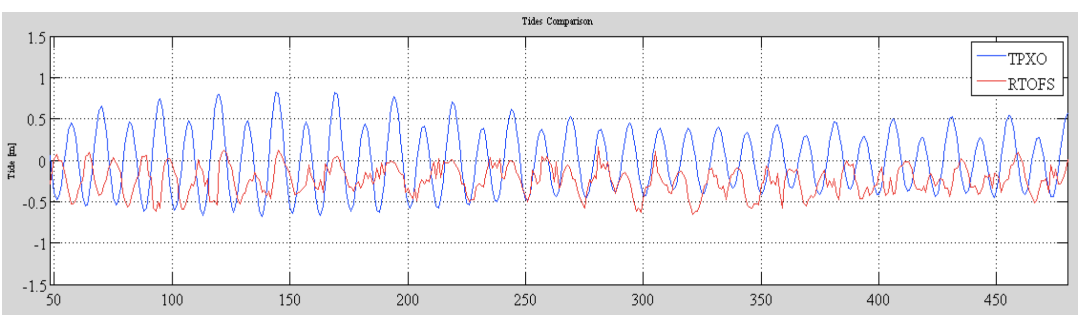
Nesting Delft3D in RTOFS

03-08 May 2012





TPXO and RTOFS Tides at SE Boundary for 03-23 May 2012



RTOFS:

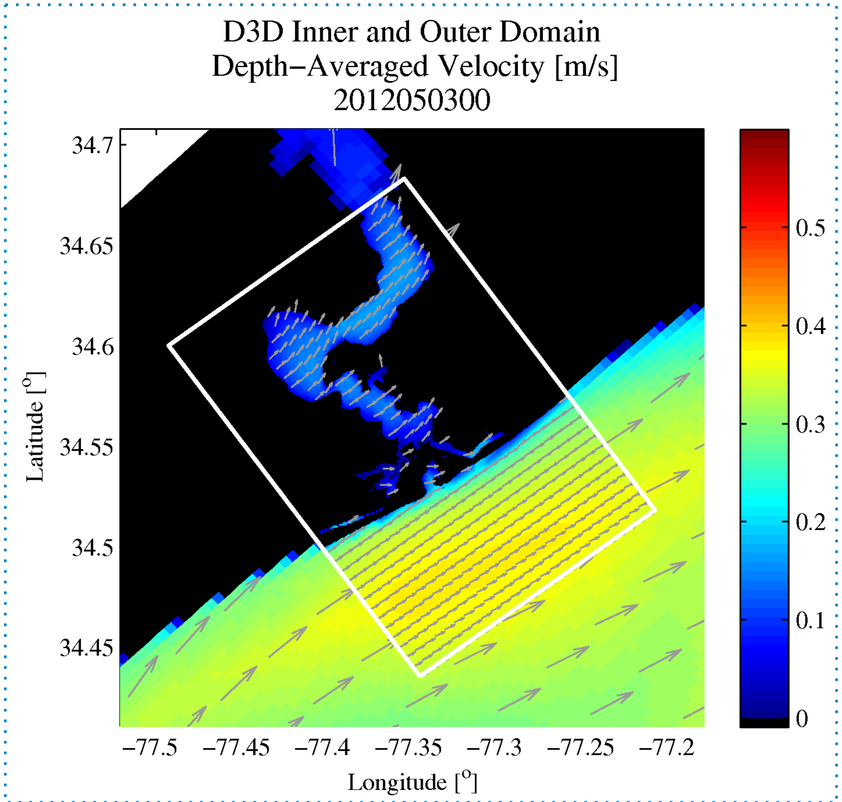
- Bathymetry: ETOPO5
- Grid resolution: 5km near the shore
- Temporal resolution: 24 hour volumetric data, hourly surface data

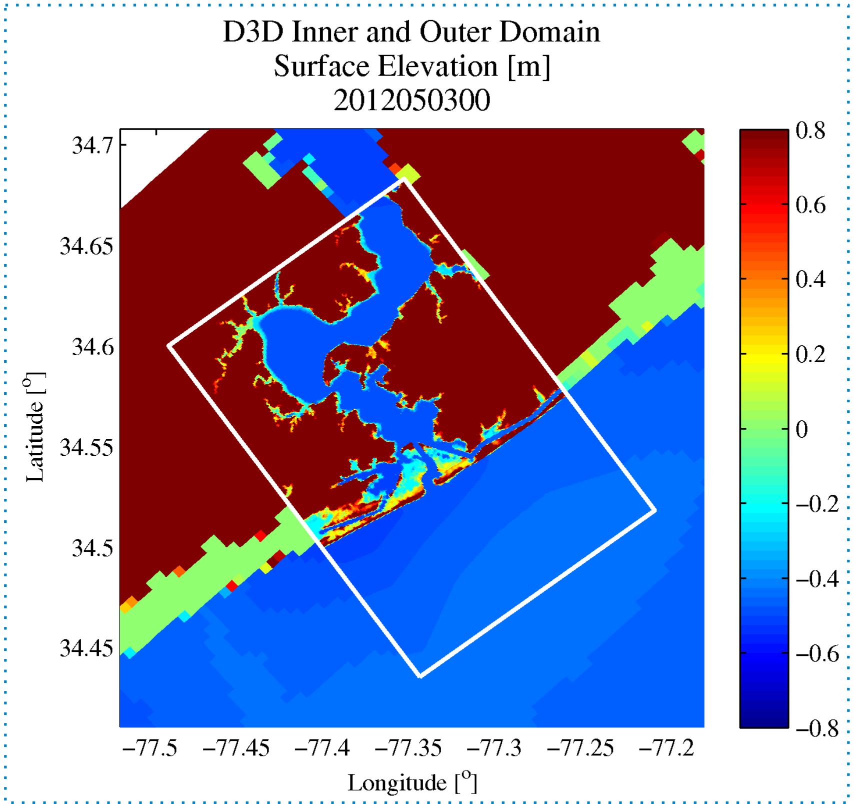
D3D:

- Bathymetry: NOAA Coastal Relief Model
- Grid Resolution: 500 m
- Temporal resolution: 15 second time step
- Boundary Conditions are interpolated from the 24 hour volumetric data to hourly volumetric data using the hourly surface information

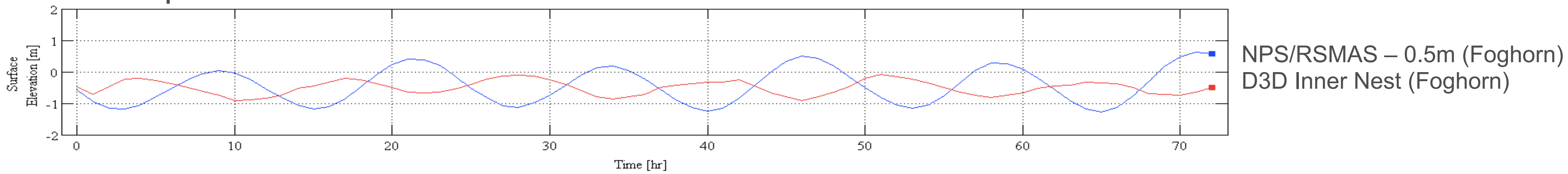
Inner Domain Nested D3D Simulation

- Time: 05-03-2012 00:00 to 05-06-2102 00:00 (73 hours)
- Time step: 15 sec   Grid: 312x454 at 50m spacing
- FWD run: 7.5min on 16 CPUs



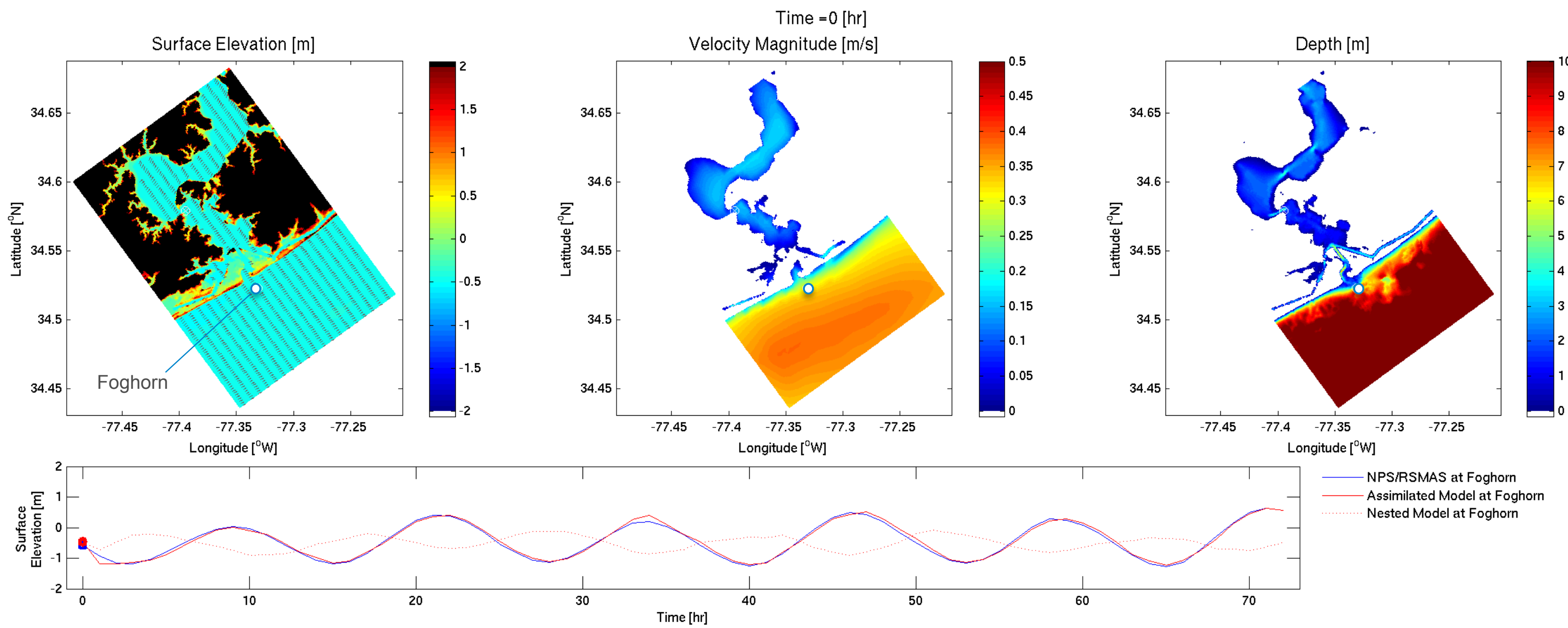


Comparison of Delft3D inner nest with NPS/RSMAS tide data



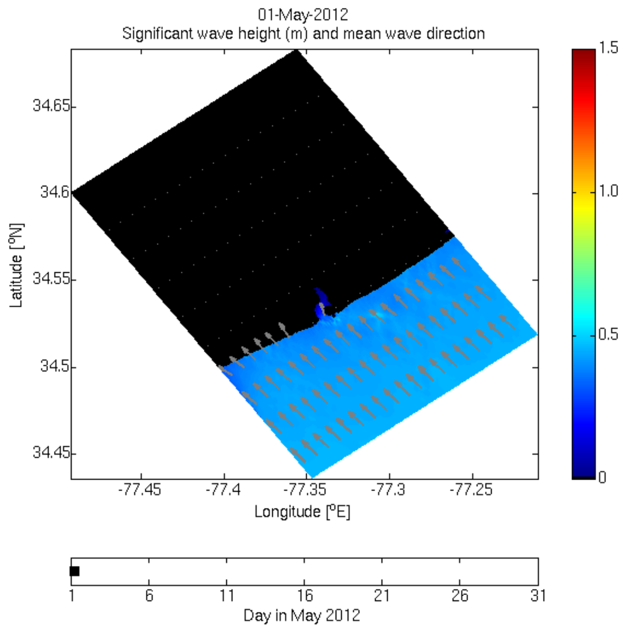
New River Inlet Inner Domain Assimilation

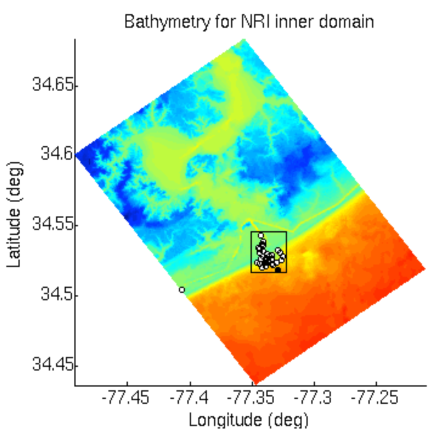
- Initial guess nested from D3D Outer Domain
- One-step correction of surface elevation component of offshore Riemann BC
- Gradient calculated from offshore boundary of adjoint solution

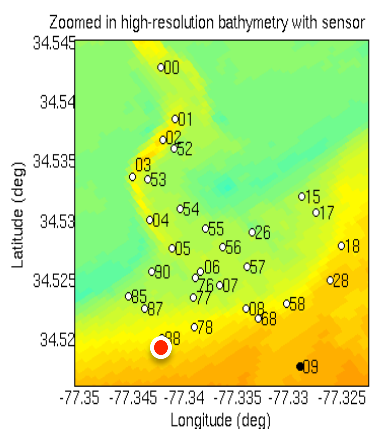


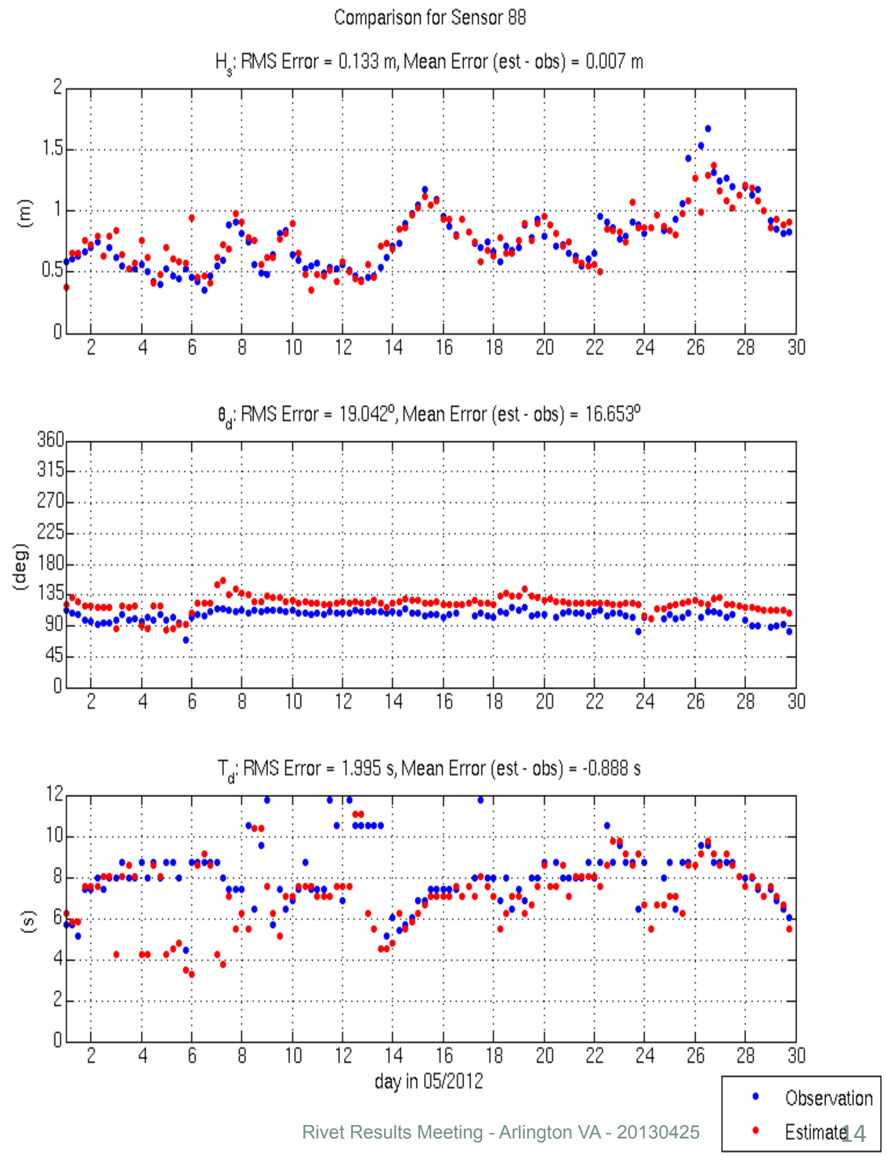
Inner Domain Wave Comparison to WHOI Tritons

Nested inner domain, outer domain BCs from Waverider assimilation



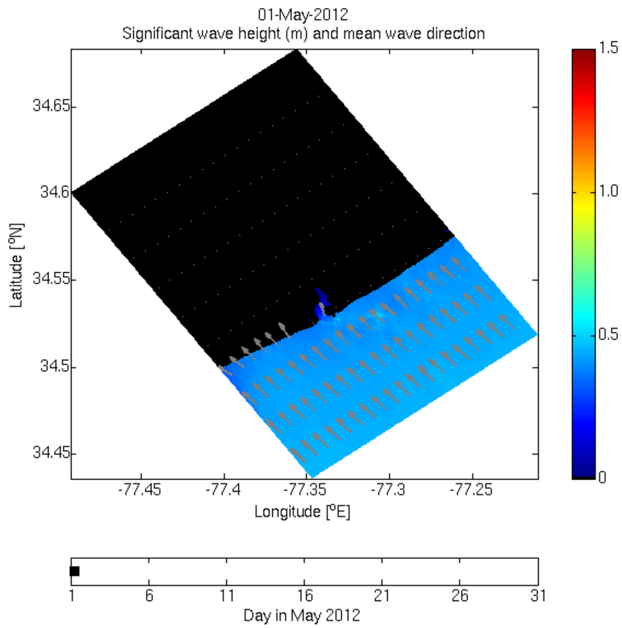


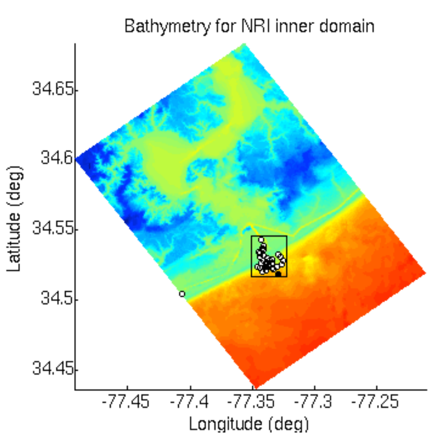


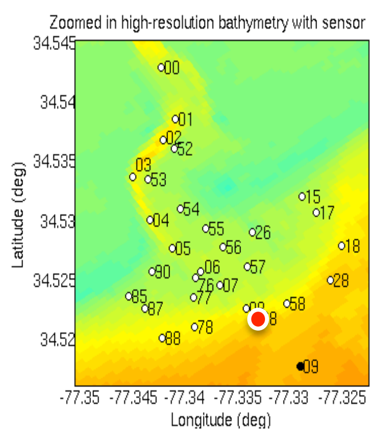


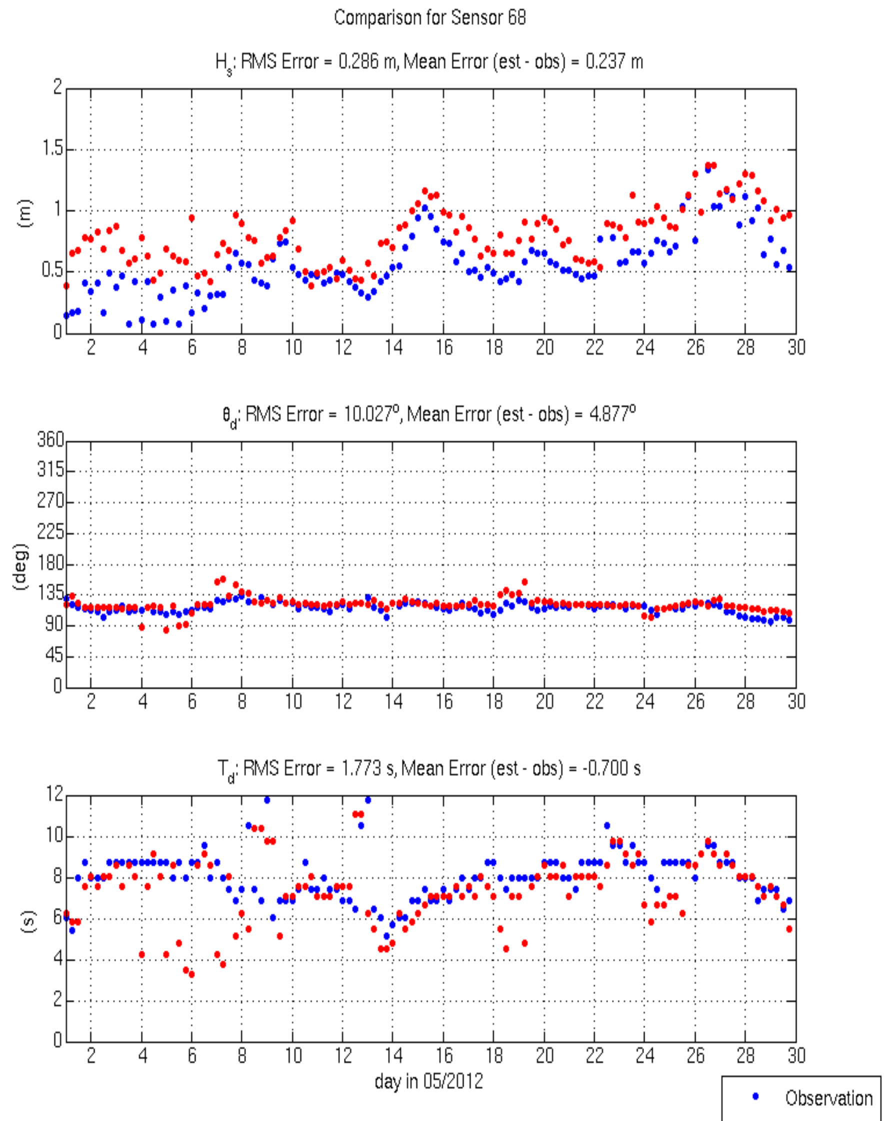
Inner Domain Wave Comparison to WHOI Tritons

Nested inner domain, outer domain BCs from Waverider assimilation



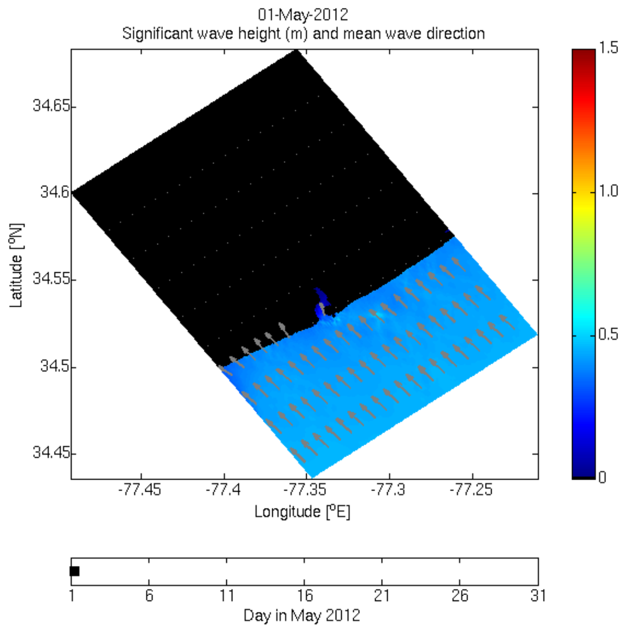


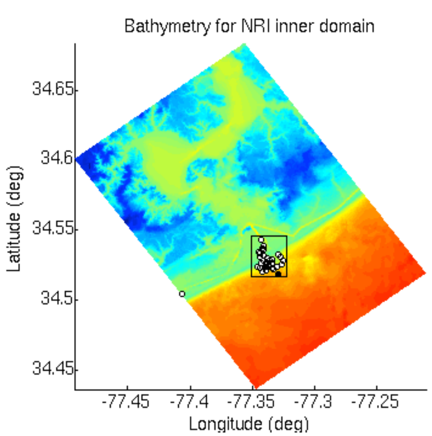


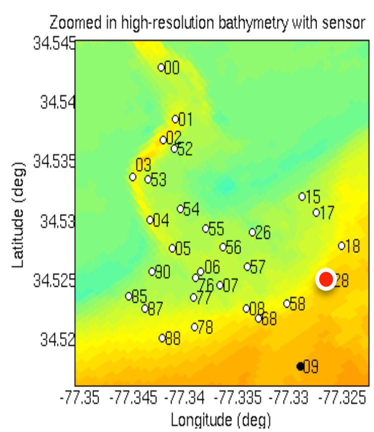


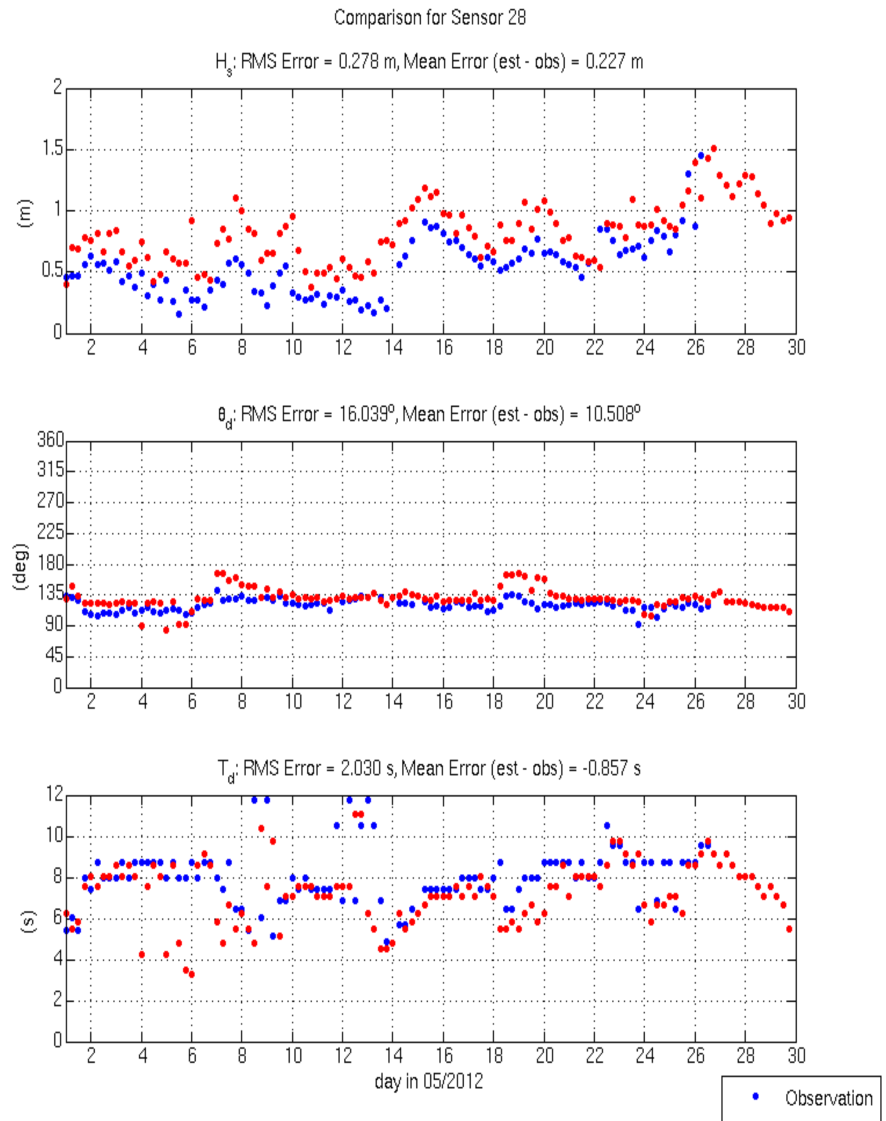
Inner Domain Wave Comparison to WHOI Tritons

Nested inner domain, outer domain BCs from Waverider assimilation



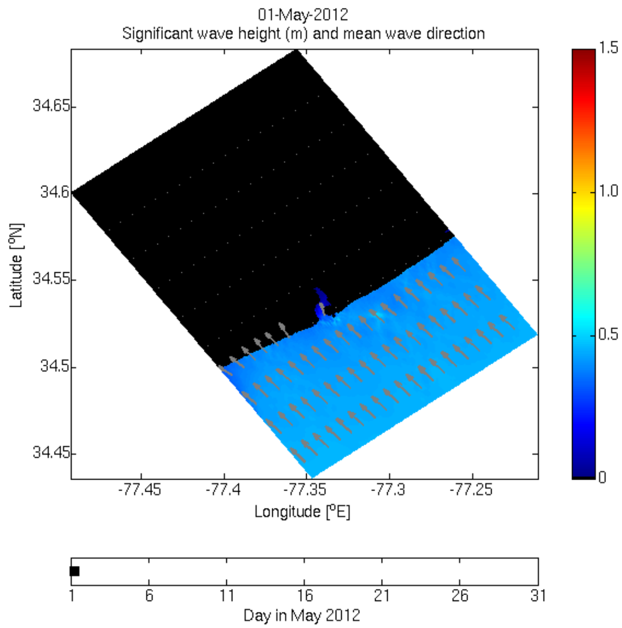


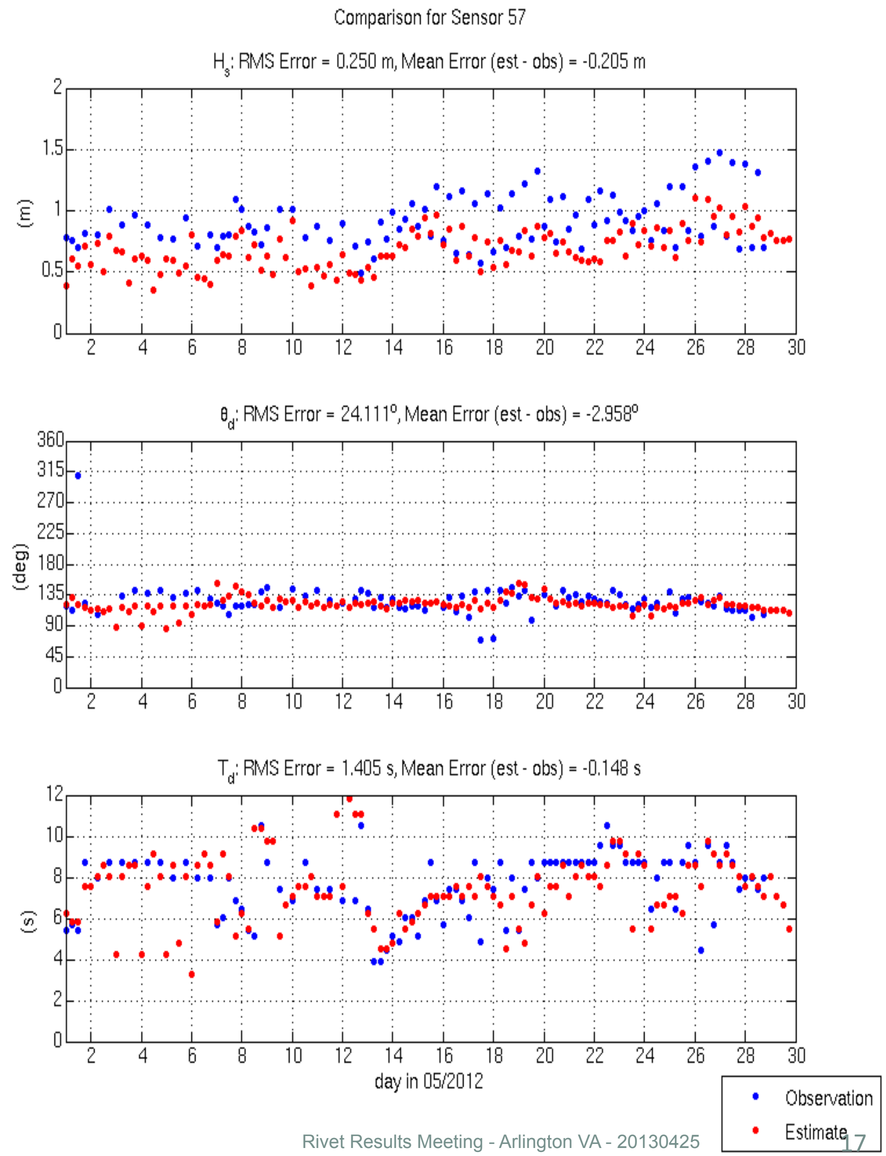


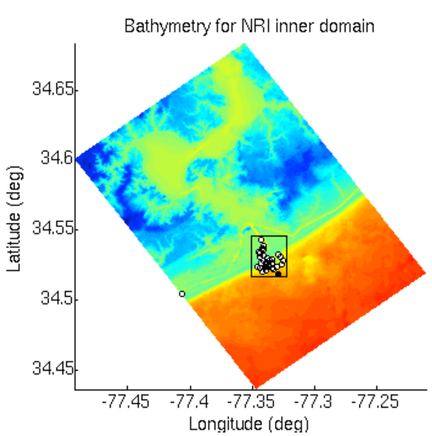


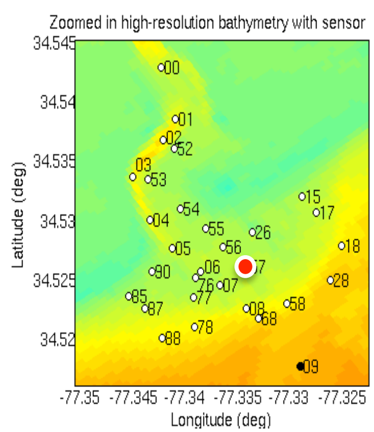
Inner Domain Wave Comparison to WHOI Tritons

Nested inner domain, outer domain BCs from Waverider assimilation









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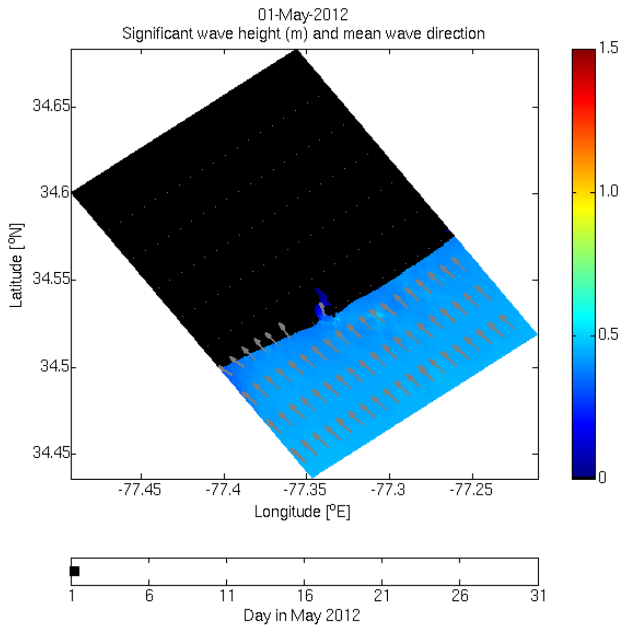
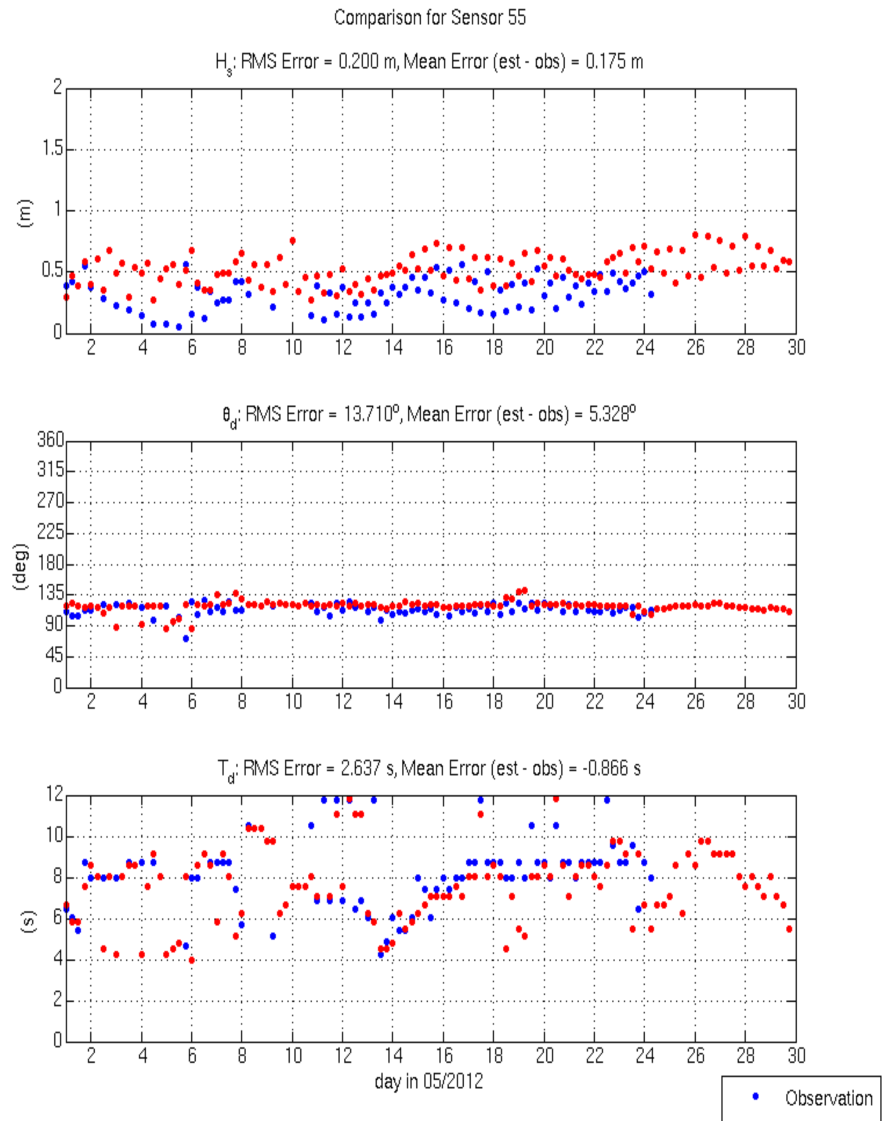
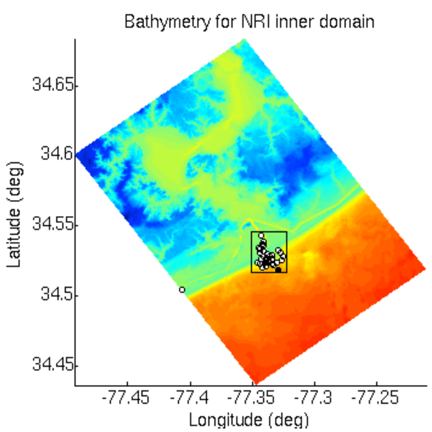
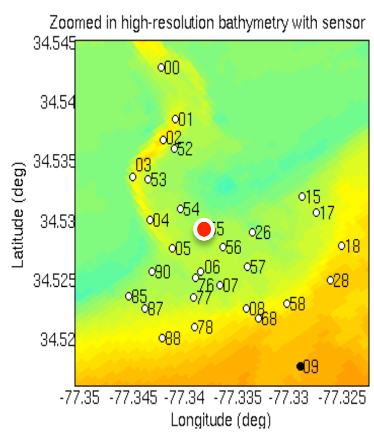
Nested inner domain, outer domain BCs from Waverider assimilation



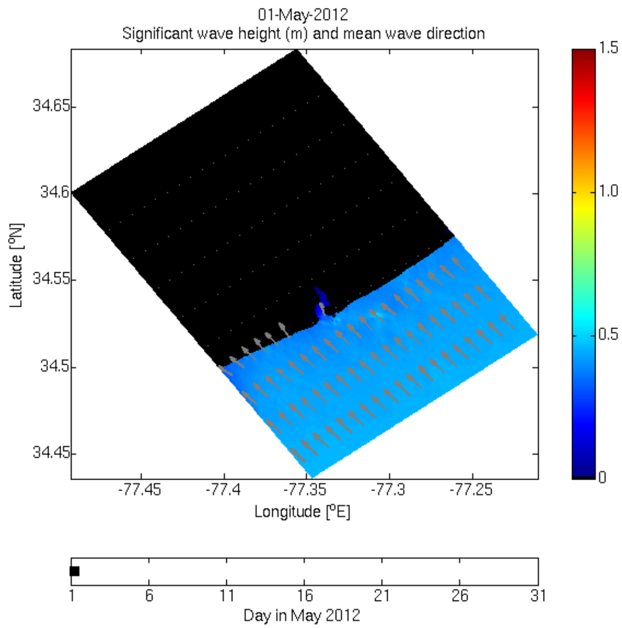


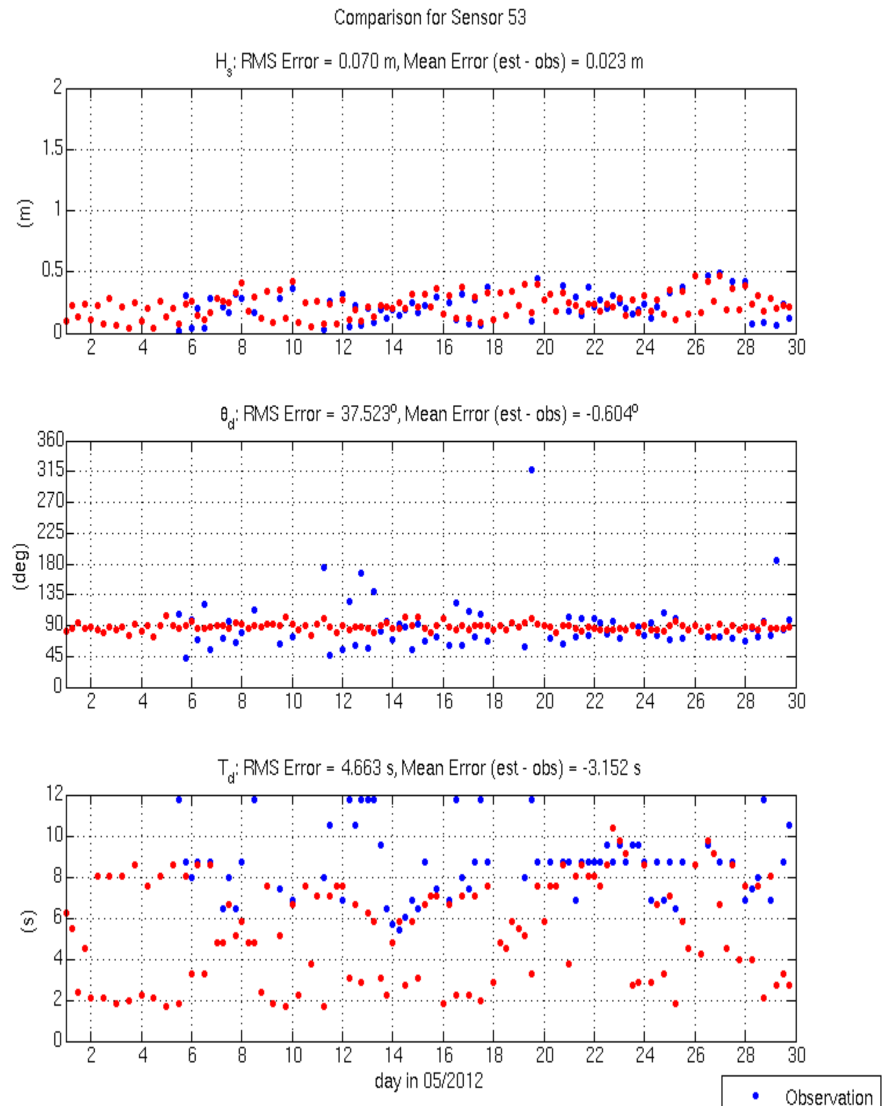


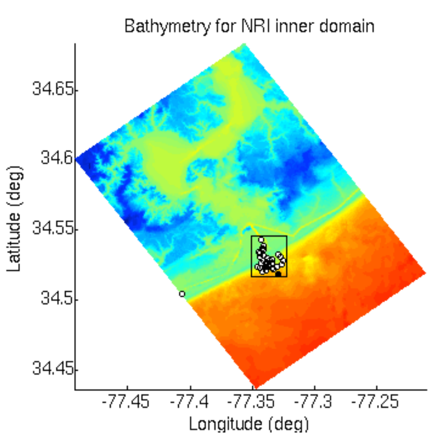


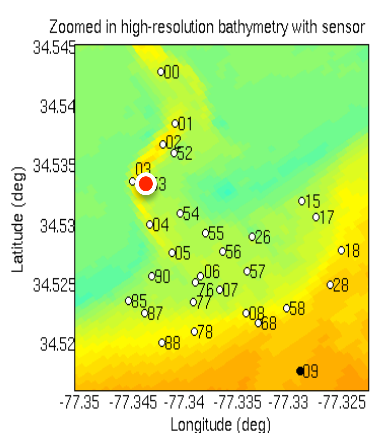
Inner Domain Wave Comparison to WHOI Tritons

Nested inner domain, outer domain BCs from Waverider assimilation









Summary and Next Steps

- Wave data assimilation in SWAN
  - Assimilation of buoy-derived Fourier directional components implemented for outer domain wave computation
  - Result compare favorably to independent data (wave direction is biggest challenge)
  - Nested inner domain solution implemented; presently being evaluated in comparison to WHOI data

- Assimilation in Delft3D-FLOW
  - Methods for nesting of Delft3D in RTOFS (and others) developed using BC based on Riemann invariants
  - Nesting necessary to capture exogenous current effects important near boundary currents
  - Inner-shelf tides from RTOFs may have issues (other quantities not clear)
  - Tides can be corrected using single-point observation via assimilation

- Next steps
  - Further validation of inner-domain wave solution in comparison to WHOI (other?) data
  - Further exploration of tide estimation from NPS/RSMAS (other?) data
  - Use of UW-APL ATI SAR data for circulation assimilation (others for assimilation/validation?)
  - Evaluation of wave/current performance in coupled computations

Thank You

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